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The New Case for a Railway to Alaska: Oil and LNG by Unitrain from the Arctic

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It has been shown in a Canadian study (2) that the logical market for Arctic oil and gas is the east central industrial area focused at Chicago. A double-track rail trunk from Prudhoe Bay up the Mackenzie Valley can deliver 3 million bbl/day of oil at Edmonton for 50¢/bbl, and 16 billion SCFD of LNG at Chicago for about 25¢ per MCF. With a second trunk from Edmonton through Rockies, Yukon and Alaska, this flow could be tripled and both costs reduced while paying all railroad construction and operating costs. Delivered at Chicago this gas would not only keep our continental pipeline network in use, but in regasification the LNG in a great meat packing area its refrigerating capacity could bring a significant economic return. Here for the first time is a genuine economic case for a railway to open up the untapped resources of the great northwest, with long term benefits far greater then Seward ever dreamed of.

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RESERVES AND THE IMPENDING NATURAL GAS CRISIS

We live in a world dependent for almost all its energy upon three fuels — coal, oil, and natural gas. Nowhere is this dependence so great as in the United States and Canada, where 7 percent of the world's people consume 40 percent of its energy resources. To fully appreciate the stiuation, it is needful to realize the magnitude of this annual appetite. In terms of energy units, our two countries in 1965 consumed 55.5 quadrillion Btu — 23 percent in coal, 46 percent in oil, and 31 percent in natural gas. In 1975, this will increase to 78.5 quadrillion — 22 percent from coal, 43 percent from oil, and 35 percent from natural gas. In actual quantities for the year 1975, this means burning 850 million tons of coal, 250 billion gal of oil and gasoline, and 26.6 trillion cu ft of gas — if that much can be found! Table 1 tells the story!

To meet the demand for coal and oil, we are fortunate. The resources we have access to are prodigious. Our domestic resources in coal measure over 500 billion tons, even though much of this is under the western plains and Alaska. In oil, our near-at-hand reserves (the gulf states, California, Alberta) would vanish in 15 years if used first. But so far, we can afford to draw upon the tenfold reserves elsewhere in the world, thanks to the unmatched economy of modern tanker transportation. In addition to this, we now have the enormous new finds on the Arctic coast of Alaska and Canada.

It is in natural gas that a crisis faces us. With proven reserves today in the 48 states and Alberta of less than 300 trillion cu ft, various authorities give us only 12 to 15 years, as reference (1)[1] graphically shows. This means that a multibillion dollar network of a million miles of pipeline, providing almost all of our domestic and industrial heating, will lie idle by 1985 unless wise and heroic measures are taken.

Here it may be argued that natural gas is not an "essential" fuel since electric power and transportation (cars, trucks, trains, and planes) are not in danger so long as coal and oil are plentiful. Yet, of the three, natural gas is, by far, the least polluting and the ideal fuel for domestic and process heat, nor can a complex industrial company contemplate the transfer of 35 percent of its fuel demand, and the idleness of so great a capital investment without traumatic readjustment and loss.

New measures are already being taken, it is true. The development of gas liquefaction (LNG) and a growing fleet of LNG tankers now makes it possible to import natural gas from Libya, Algeria, and Venezuela along with petroleum. Yet, all such tankers, both built and ordered (11), will scarcely supply 1.5 percent of today's demand — not to speak of tomorrow's! Moreover, the LNG tanker, carrying a volatile liquid at -260 F in an ocean 320 deg hotter, becomes a very sophisticated structure, costly to build and operate, and losing as much as 10 percent of its precious cargo in "boil-off" while enroute. Ingenious as the LNG tanker is, it alone cannot avert both a serious cutback in our gas consumption and an equally serious price rise.

In short, until the dramatic recent discovery of giant[2] oil and gas reserves along the Arctic coast, the most serious fuel crisis before us was how to maintain our continent-wide gas supply. Now, thanks to this discovery, the picture has changed. The finest and most automatic fuel distribution system the world has ever seen, our continental pipeline network, can now hope

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[1] Numbers in parentheses designate References at end of paper.

[2] The Prudhoe Bay oil reserves have been estimated upward from 10 billion barrels (proven) to 100 billion possible; and the gas reserves from 26 trillion cu ft proved to 400 trillion possible. The Mackenzie R delta reserves are judged to be equal or greater (3, 5).

Table 1 Energy consumption in U.S.A. by major use categories in trillions Btu's

	Coal	Natural Gas	Oil & Oil Products	Hydro	Nuclear	Total
			Household and Commercial			
1955	1,775	2,850	4,001	-	-	8,626
1965	625	5,534	5,634	-	-	11,793
1975	460	8,430	6,700	-	-	15,590
1985	400	11,650	7,800	-	-	19,850
			Industrial			
1955	5,849	4,675	3,329	-	-	13,853
1965	5,689	7,685	4,141	-	-	17,515
1975	7,095	12,200	5,370	-	-	24,665
1985	8,160	14,200	6,800	-	-	29,160
			Transportation			
1955	474	254	9,109	-	-	9,837
1965	19	518	12,184	-	-	12,721
1975	20	700	18,000	-	-	18,720
1985	20	800	23,300	-	-	24,120
			Electric Energy Generation			
1955	3,484	1,194	512	1,497	-	6,687
1965	5,880	2,399	743	2,050	38	11,110
1975	8,520	3,770	940	2,580	4,260	20,070
1985	11,300	4,850	1,070	3,200	15,500	35,920
			Miscellaneous			
1955	123	260	572	-	-	955
1965	145	-	507	-	-	652
1975	145	-	710	-	-	855
1985	120	-	830	-	-	950
			Total Gross Energy Input			
1955	11,705	9,233	17,523	1,497	-	39,958
1965	12,358	16,136	23,209	2,050	38	53,791
1975	16,240	25,100	31,720	2,580	4,260	79,900
1985	20,000	31,500	39,800	3,200	15,500	110,000

for a new lease on life. A Canadian study (2) has already shown that the logical market for the Arctic oil and gas is the east central industrial area, focused on Chicago, rather than California as often assumed. Nevertheless, while the objective is to keep the present continental pipeline network in use, it does not necessarily follow that a pipeline is the most economic long-term means for transporting Arctic oil and gas to this network whether it enters the network at Edmonton or even at Chicago.

IMPORTANCE OF REACHING THE BEST LONG-TERM SOLUTION

With the gas crisis so far advanced, and growing uncertainty of access to foreign oil, there may be no question that the immediate emergency demands at least one pipeline from the Arctic as rapidly as possible. But it is equally important that such a crash program should not unduly influence the choice of the best long-term solution for developing the total resources of the great north, nor should it deter us from evaluating all possible alternatives in making this choice.

Among these alternatives, the railroad is usually dismissed as ineconomic for oil and totally impractical for gas. Reference (2) has evaluated conventional tanker trains of oil from the Arctic to a terminal at Trout River, NWT with a 650-mile pipeline from there to Edmonton, which proves barely competitive. But two new technologies have changed this picture: natural gas liquefaction and continuous unitrain operation. The railroad alternative must then be thought of in terms of a daily fleet of continuously moving unitrains of both oil and LNG, the latter propelled entirely by the natural gas boiloff, as

Table 2

1200-MILE* RAILWAY TO THE ARCTIC
OIL AND LNG DELIVERY CAPABILITIES

	PHASE A BASE FLOW	PHASE B 5-FOLD	PHASE C 10-FOLD
LNG DELIVERY: 10^6 lb/day	140	700	1,400
MMSCF/d	3,000	15;000	30,000
Fraction of U.S. demand today	5%	25%	50%
OIL DELIVERY: 10^6 lb/day	190	950	1,900
1,000 bbl/d	600	3,000	6,000
Fraction of U.S. demand today	2.5%	12.5%	25%
CARS/TRAIN** LNG	118	140	165
OIL	102	120	140
TOTAL	220	260	305
LNG TANK CAR			
Cap'y. U.S. Gals	34,000	34,000	40,000
Weight, app.gross tons	80	80	95
OIL TANK CAR			
Cap'y. U.S. Gals	25,000	25,000	30,000
Weight, app. gross tons	125	125	150
TRAIN SPEED (avge) mph	50	55	60
TRAIN LENGTH miles	2.6	3.1	3.7
TRAINS PER DAY NEEDED	10	42.5	72
TRAIN INTERVAL minutes	144	34	20
TRAIN SPACING miles	120	31	20
TRAIN HEADWAY miles	117.4	27.9	16.3
ROLLING STOCK NEEDED (for 1 hr. loading & insp'n per train + 10% spares)			
TRAINS	24	90	140
LNG CARS	2,732	12,600	23,100
OIL CARS	2,448	10,800	19,600
LOCOMOTIVES (5 per train)	120	450	700

* Based on the primary trunk proposed in Table 3, and Fig. 1 Valleyview, Alta to Ft. McPherson, NWT South of Valleyview or Edmunton oil would move by pipeline. North of Ft. McPherson traffic divides between Alaskan and Canadian sources.

** Separate trains of LNG and crude oil may also be considered, the LNG trains propelled by gas turbine power, and the oil trains by diesel.

are the LNG ships.

It is the purpose of this paper to show that such an alternative can not only deliver both fuels from the Arctic coast to Edmonton and even Chicago at less cost than pipelines, but can also serve to open up the resources of Alaska and the Canadian northwest in a way no other means can, by providing a railroad that pays its way from its very inception.

In short, with the discovery of Arctic oil and gas, we have, at long last, an overwhelming economic case for railroad service to Alaska with long-term benefits far greater than Seward ever dreamed of.

PRELIMINARY EVALUATION OF ALTERNATIVES

The ocean tanker alone can be dismissed at once. Access to the Arctic coast would be limited to a very few deep harbors, none of them ice-free nor close to the oil resources, or it would demand prodigiously expensive mooring facilities far out from the shallow coast, and even these not ice-free. Above all, no inland resources or communities could be served in any way.

A highway system, even if limited to a 2000-mile Edmonton-to-Alaska-to-Arctic freeway, would entail such a vast fleet of trucks to deliver the required amount of oil or gas, as to make the highway almost useless to other traffic. Further, it is not difficult to show that the capital investment in trucks, highway, and service facilities, plus the premium labor costs involved over such vast and forbidding terrain, could not hope to deliver oil and gas competitive-

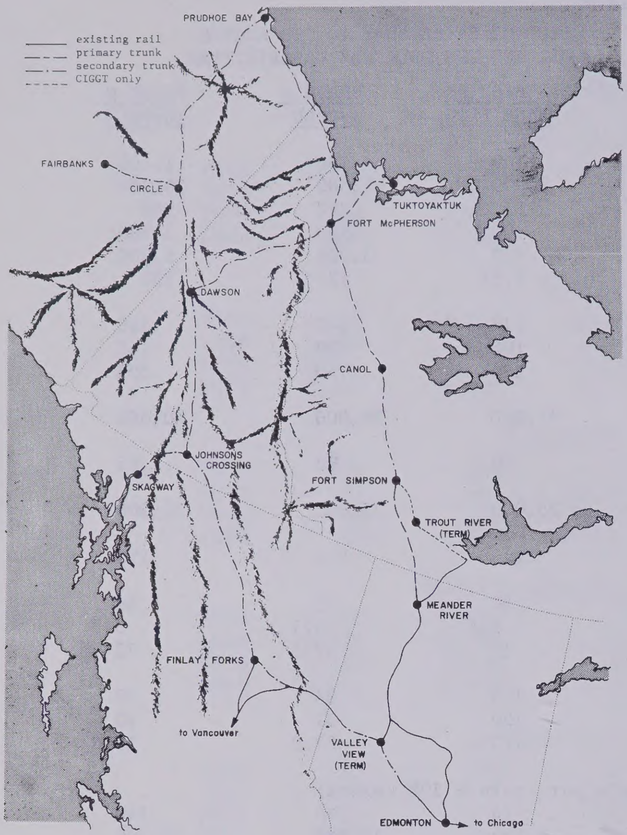


Fig. 1 Alternative rail routes to the Arctic

ly with rail or pipeline. (At the same time, it must be recognized that a basic highway system will eventually come to the northland regardless of any other form of transportation, just as it has come elsewhere.)

The pipeline, though an obvious choice for oil or gas, is essentially a single-purpose carrier, useless when the oil and gas are gone. Perhaps a slurry of pulverized ore and oil might be conveyed, but beyond that nothing else. Again, pumping oil through such a great distance at low-temperature calls for prodigious power and pressure, with serious consequences in the event of power failure or pipeline rupture, unless a parallel independent pipeline is provided. Finally, a pipeline can, in no way, enhance or prosper existing or new communities enroute, or stimulate the development of other inland resources.

There remains the railroad, transporting oil, and liquefied natural gas by a fleet of continuously moving unitrains, as described in the foregoing and, at the same time, able to furnish rail service for most other commodities enroute. Here, because of the enormous and proven ton-mile capacity per investment dollar, plus the 600:1 volume reduction in liquefying natural gas, plus the remarkable economies achievable in automatic operation of long unitrains, the railroad now appears to be a competitor to the pipeline with many additional advantages as well.

For it is clear that if the railroad with oil and LNG unitrains can deliver the needed oil and gas at the same cost as a pipeline, the same trackage, and perhaps even the same trains, might serve to transport both people and other commodities anywhere in the system at incremental costs alone, i.e., at rail tarriffs less than anywhere else in the country! Conversely, the total cost of moving oil and gas by rail may be diminished by the other reserves and long-term benefits generated by the railway.

PERFORMANCE COMPARISON: PIPELINE VERSUS OIL-AND-LNG UNITRAIN

We consider first the pipeline system that would be needed to deliver 3,000,000 mscf/day of gas plus 600,000 bbl/day of oil from the North Slope to Chicago. (Note: 600,000 bbl/day is the initial flow rate planned for the trans-Alaskan pipeline, and 3,000 mmscf/d represents about the same heating value in gas and about 5 percent of our present national consumption.)

The foregoing demand would require two parallel 48-in.-dia natural gas lines operating at 1000 psi and 20 fps, plus a third 48-in.-dia oil line flowing at 3 fps. Total distance would be some 3200 miles, 1700 miles of new lines from Prudhoe Bay to Edmonton, plus 1500 miles to Chicago using existing lines. Total pumping power for the three lines north of Edmonton would be about 2.5 million horsepower, depending on the time of year. The total transportation cost, counting fixed charges, maintenance, and pumping costs, would be about $1.25/bbl for the oil, and about $1.00/mcf for the gas (9).

We now consider the same daily delivery of each fuel in unitrains loaded at the North Slope, unloaded in Chicago, with continuous transit at 50 mph on a double-track system. 140 million lb/day of LNG at 26 lb/cu ft, and 190 million lb/day of oil at 56 lb/cu ft must be delivered. This would call for 1160 34,000-gal LNG tank cars (maximum car volume presently allowed by D.O.T.) and 1020 standard 100-ton tank cars each day, or ten 220-car trains per day, running 144 minutes apart, 120 miles between trains, and covering 1200 miles per day assuming both LNG and oil in the same train.

Each train would be propelled over its

entire round-trip journey by the boiloff of less than 2 percent of its gas cargo consumed in the locomotives, so that 118 LNG cars loaded at the Arctic would deliver 116 cars of LNG plus the entire 102 cars of oil at Chicago. We have thus established the capability of a single railroad by use of oil-and-LNG unitrains to match the combined delivery of a 48-in. oil pipeline (600, 000 bbl/day) and two 48-in. gas lines (3000 mmscf/d). In the economic analysis, later it will be shown that even at these limited flows, the delivered cost by rail is competitive.

Of even greater economic importance is the ability of the railroad to increase this capacity as much as tenfold without any additional capital cost, except for rolling stock as shown in Table 2. In addition, the railroad can continue to serve as a common carrier to all points on its route, and finally, when the oil and gas resources are depleted, it remains both fully useful and essentially paid for. As already observed, none of these three capabilities are found in a pipeline system.

Looking at Table 2, it is, of course, apparent that operation of a 1200-mile railroad trunk at Phase C capacity, i.e., 60 mph continuously moving 300-car trains round-the-clock at 20-min. spacing, would entail the most sophisticated automatic maintenance, control and terminal handling, not to speak of new engineering to achieve year-round derailment-free operation.

Such traffic density and control has already been achieved in railroad technology, during short periods of the day. The challenge here is to maintain it day in and day out over vast stretches of northland in the most rigorous climate without a single derailment, collision, fire, or power failure. With such massive quantities of hazardous cargo rolling at such speeds, the economic incentive to avoid such accidents is enormous.

Before considering the engineering details of train design, terminal facilities and track design and maintenance to achieve this, let us look at the geographical alternatives for the proposed system.

SELECTION OF OPTIMUM RAIL NETWORK

The optimum rail network to tap the Arctic oil reserves, the Mackenzie valley resources and the mineral resources of the northern Rockies and Alaska, will clearly develop along two trunk lines, an easy primary trunk from the Edmonton area down the Mackenzie to its delta, and a more costly later trunk through northern British Columbia and the Yukon territory.

The proposed system is shown in Fig. 1, and its mileages tabulated in Table 3 and compared with the CIGGT system of reference (2).

At the northern end, Alaskan hot oil and liquefied gas would be loaded at Prudhoe Bay, while unitrains of Mackenzie delta oil and LNG would commence at either Fort McPherson or near Tuktoyaktuk. Permafrost and environmental conditions in the delta would dictate whether rail or pipe should be used for this link.

At the southern end, the obvious terminal for transferring rail-borne oil to the continental pipeline network is the point where the two trunk lines from the north best converge. This is found to be at Valleyview, Alberta, about 200 miles northwest of Edmonton. By comparison, the CIGGT study of reference (2), assuming conventional train operations, chose as southern oil terminus at Trout River, N.W.T., requiring 650 miles of new oil pipeline from there to Edmonton plus 140 miles of access rail from Enterprise. The greater economy of automatic unitrain operation proposed here justifies Valleyview over Trout River, as well as the fact that it gives better rail access to Edmonton and south for the LNG shipments.

Movement of LNG by rail, being more closely competitive with a gas pipeline than is rail-borne oil with an oil pipeline, should clearly proceed further south than Valleyview. The ultimate goal for much of it is the Chicago area (2), 1500 miles beyond Edmonton, and in regasification at Chicago for further distribution by pipeline, we find the maximum economic benefits.

Looking now at the proposed rail system north of Valleyview, the primary trunk of 1620 miles to Prudhoe Bay would follow much of the route proposed in reference (2), via the Mackenzie Valley to Ft. McPherson and thence along the Arctic coast.

This route would entail only 1370 miles of new rail, plus some 350 miles of rail or pipeline at north and south as discussed earlier. It would avoid almost all mountainous terrain and, therefore, could achieve ruling grade less than 1 percent and curvature less than 2.5 deg per 100 ft without great cost. Continuous permafrost conditions (Fig. 2) would only be encountered north of Ft. McPherson, along the Arctic coast where its protection would be easy.

Deep cuts and avalanche or flooding conditions could also be readily avoided, and the Mackenzie would only need bridging at two places. A double-track roadbed on this route should thus be constructible with modern heavy equipment at less than $1,000,000/mile and in less than 5 years.

By 1985, the primary trunk would be ap-

Table 3

PROPOSED ROUTES

(See Fig. 1)

Link	Commodity	Mode	Approximate Mileage		
			Existing	New	Total
A. PRIMARY SYSTEM					
1. Chicago-Edmonton	LNG oil	Rail Pipe	1,500	0	1,500
2. Edmonton-Valleyview* (*oil unitrain terminal)	LNG oil	Rail Pipe	105 1,605	95 95	200 1,700
3. Valleyview-Meander R.	Both	Rail	250	50	300
4. Meander R. - Ft. Simpson	Both	Rail	0	250	250
5. Ft. Simpson-Canol	Both	Rail	0	330	330
6. Canol-Ft. McPherson* (*junction from Tuktoyaktuk and Dawson, Yukon)	Both	Rail	0	280	280
7. Ft. McPherson-Prudhoe Bay	Both	Rail	0	460	460
			250	1,370	1,620
8. Ft. McPherson-Tuktoyaktuk	Both	Rail or pipeline	0	170	170
B. SECONDARY SYSTEM					
9. Valleyview - Finlay Forks* (*rail jct. to Vancouver)	Both	Rail	85	240	325
10. Finlay Forks - Johnson's Cross.* (*pipeline to Skagway)	Both	Rail	300	200	500
11. Johnson's Cross.-Dawson* (*rail jct. to Ft. McPherson)	Both	Rail	0	340	340
12. Dawson-Circle* (*rail jct. to Fairbanks, 150m.)	Both	Rail	0	225	225
13. Circle-Prudhoe Bay	Both	Rail	0	380	380
			385	1,385	1,770
14. Dawson-Ft. McPherson	Both	Rail	0	300	300
C. SYSTEM PROPOSED BY CAN INST. OF GUIDED GROUND TRANSPORT (Ref. 2)					
1. Edmonton-Trout River, NWT (oil train terminal)	oil	Pipe	0	650	2,150
2. Trout R. - Prudhoe Bay	oil	Rail	0	1,240	1,240

proaching its peak capacity of 50 trains a day delivering 800 million lb of LNG and 3.5 million barrels of oil, (Table 2, Phase B). In addition, it would have served to open up other mineral and fuel resources up the Mackenzie Valley, such as at Canal and the Athabasca tar sands. Thus, by 1985, it would be imperative to add more trackage, and equally imperative that this new trackage should, at the same time, give access to the resources of northern British Columbia, Yukon and Alaska. Hence, the "secondary" trunk, shown in Fig. 1 and Table 3, proceeds northwest from Valleyview and up the Finlay River Valley to make maximum use of the Peace River railroad and the proposed extension of the Pacific Great Eastern to Dease Lake, B.C. At Johnson's Crossing, Yukon, there would be rail or pipeline access to the ocean at Skagway. Near Dawson, a 300-mile branch almost due north would link the secondary trunk to Ft. McPherson and the Mackenzie delta resources, and west from Circle on the Yukon, a 150-mile rail link would reach Fairbanks and the Alaska Railway. Four hundred miles beyond Circle, the main line would reach Prudhoe Bay via river valleys and a tunnel through the Brooks Range. [Reference (2) shows one such route through this range involving a 7.5-mile tunnel at 3000-ft elevation and thence down the Sagavanirktok River)].

With the completion of the secondary trunk, and the Dawson-Ft. McPherson link both the two great Arctic oil resources could be carried to Valleyview by either or both trunks as seen in Fig. 1. Thus, completion of the secondary trunk, though involving some 1700 miles of new rail with several mountain passes, would double the potential delivery rate from both reserves, would permit each trunk to serve as an emergency alternate to the other, and most important of all, it would give direct rail access from the United States heartland to Alaska, with Fairbanks only 3200 miles or 55 hr from Chicago for almost any commodity. With such benefits, the increased cost of the second trunk would be easily justified.

ENGINEERING OPTIMIZATION OF THE SYSTEM

In projecting a 5-billion dollar investment in an entirely new 4000-mile railway system to serve a vast untapped territory, it would be an inexcusable blunder to perpetuate the railroad design and operating errors of the past rather than make a clean start wherever new technology dictates what is best. In short, where construction and repair are costly and maintenance of service is paramount, engineering optimization is imperative.

Consider, for instance, that each proposed unitrain represents a capital cost of some $6,000,000, and that by 1985, the system will be delivering oil and gas alone worth $50,000,000 per day to the United States market. An accident-free system is, therefore, an engineering priority.

The normal accident record for class 1 United States railroads today is:

1 One minor derailment per 200,000 train miles, with a 6-hr delay, no track or train damage
2 One major derailment per 1,250,000 train-miles, with 48-hr delay, both track and train damaged.

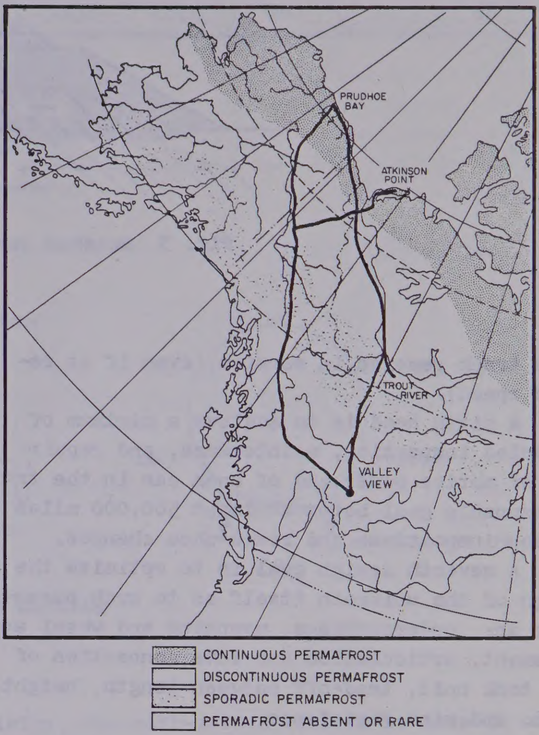


Fig. 2 Approximate limits of continuous and discontinuous permafrost zones, western North America

Train-stopping accidents of this frequency would be totally unacceptable in the proposed system and should be reducible to less than 1 percent of the United States average by fundamental study and redesign of their causes, the principal ones being:

1 Standard track gage of 4 ft-$8^{1}/2$ in. is too narrow for ultra-heavy rolling stock with center-of-gravity much higher than one gage length; a gage of 7 ft-0 in. is desirable.
2 Standard wheels of 33 in. with 2-in. flanges are too large for high-speed track-holding with long trains, curves, and swiveling trucks.
3 Bearing, wheel or axle failures.
4 Track failures: splitting, separation, or misalignment at joints.
5 Roadbed failures: failure of ties, or undermining of ballast.
6 Roadbed unevenness, setting up resonant lateral vibration in cars.

The second engineering objective in such a system is a low maintenance right-of-way, and a means of replacing ties and cleaning ballast

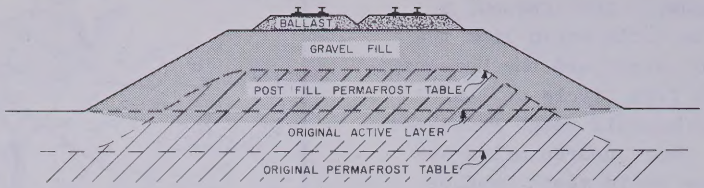


Fig. 3 Roadbed construction over permafrost

while track remains in service (even if at reduced speed).

A sixth need is to achieve a minimum of scheduled inspection, maintenance, and repair both of motive power and of each car in the train, a reasonable goal being at least 500,000 miles between inspections and brake-shoe changes.

A seventh design goal is to optimize the design of the unitrain itself as to such parameters as: undercarriage, mounting and wheel arrangement, articulation and interconnection of each tank unit, tradeoff between length, height, width, and wind resistance.

SYSTEM DESIGN FEATURES

We now describe some design features by which the foregoing objectives could be approached.

Right of way

Roadbed: Frost-free well-drained ballast, no breakage of tundra, construction over permafrost as per Fig. 3. Double-track throughout network and 15-ft spacing, center-to-center each roadbed.

Track Gage: 7 ft-0 in., or 50 percent greater than "standard" gage. (Note: The initial "system" would include a 7-ft gage double-track extension from Valleyview, Alta., to Minneapolis or Chicago along existing roadbed that could be pre-empted for LNG unitrain traffic.)

Tracks: All-welded and bolted to the ties; 130-lb P.S. rail or equivalent.

Crossover Tracks: These would be provided every 100 miles for emergency single-track operation and would include a four-mile-long trailing middle track for maximum safety.

Ties: Ultra-long life treated wood, or a fibrous synthetic. Ruling grade compensated for curvature: 2 percent for 2 miles, 1 percent for 5 miles, 0.5 percent over 5 miles.

The exact ruling trade used would be the result of a complex optimization between motive power, train weight, curvature, superelevation, grade, and length of grade. The argument is that train momentum can be counted on to carry the train over a grade it might not negotiate from standstill, and involves a further tradeoff between capital investment in motive power and capital saving in larger permitted grades.

Level Crossing: none would be allowed either for road or rail traffic, since the ultimate frequency of rail traffic would prohibit it.

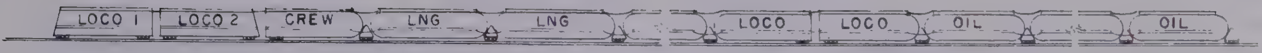
Unitrain capacity (Phase A) -- oil string: 2,500,000 gal loaded at 170 F, in 100 tanks; LNG string: 4,000,000 gal insulated at -260 F, in 120 tanks. Each tank unit forms the interconnecting link between its front and rear trucks, thus providing both traction and storage as shown in Fig. 4.

Motive Power: Four 3000-kw regenerative gas turbine-electric locomotives, two at front end and two after last LNG tank, supplying 10,000 kw to a 50-hp electric motor on the center axle of each six-wheel truck between tanks along the train, plus 500 kw to wheel motors in each locomotive.

LNG Tanks: These are 11 ft-0 in. O.D., 9 ft-6 in. I.D., and 67 ft-6 in. across heads, with a glass or 9 percent Ni steel liner and 8 in. of high-strength insulation. Each LNG tank is interconnected at each bottom end through a 6-in. I.D. internally insulated flexible hose with quick-disconnect joint, and at the top end through a smaller similar hose. The lower connections make it possible to drain the cargo from two or three points along the train. The upper connections carry the boiloff gas at low pressure (1 or 2 psig) to the locomotives to fuel the gas turbines.

Oil Tanks: These would be about 10 ft-0 in. O.D. but without internal insulation, and only 47 ft over tank heads. A lower flexible hose connection between tank ends permits draining or filling the entire string from a few points.

Intertank Trucks: These would be six-wheel units, with a 50-hp motor integrally mounted on the center axle with 36-in. wheels to give ample motor clearance. Front and rear axles carry 24-



WHOLE TRAIN VIEW

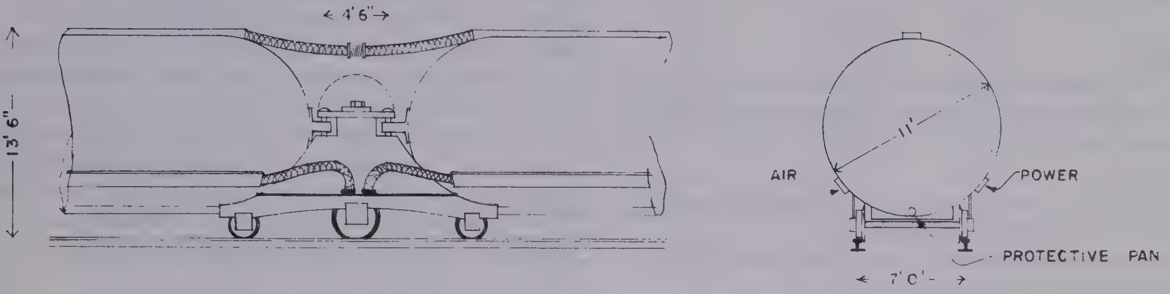


Fig. 4 Unitrain details

in. wheels, with a 14-ft overall wheel base, to give the added tracking stability necessary to minimize derailment.

Each wheel may be shoe-braked, using conventional pneumatic equipment, or each axle head may drive a hydraulic pump to act as a hydrostatic brake, which would give almost lifetime performance. Each axle would be independently sprung and mounted in roller bearings.

As shown in Fig. 4, each tank is supported on the truck by a massive "eye" in its dome, which is free to swivel about a vertical pin which also couples it to the truck.

By this type of design, the center of gravity of a loaded tank is only some 7 ft above the rail. In combination with the 7 ft-0 in. track gage, this will greatly minimize derailments. Safety is further enhanced by this means of articulating the train, since, like the Talgo train, traction or braking on a curve pulls the inner wheel against the rail where its flange is rising.

Any tank linking the unitrain may be removed for repair or other purpose by simply lifting it vertically off its coupling pins, after disengaging its hoses.

AUTOMATIC SYSTEM OPERATIONS

As indicated in reference (12), one of the economic imperatives for the future of the entire United States railway system is total automation. Next to a pipe for fluids, and a wire for electricity, the rail-guided vehicle is made to order for automatic transportation, especially for homogeneous cargo to be moved from a given origin to a given destination.

In the case of a completely new rail system to bring LNG and oil from the Arctic, it is, therefore, a prime objective to employ man power only for supervision, maintenance, repair, and emergencies.

Operations to be fully automated are as follows:

1. Loading of both LNG and oil at the northern terminals
2. Start-up and safe entrance from siding to mainline
3. Steady running and proper braking to maintain safe speed and headway
4. Switching for normal route changes and for final delivery terminal
5. Attachment of discharge hoses and unloading of cargo.

The greatest economies in automatic operation would appear in manning the system. With non-stop, 1620-mile operation, no intermediate way stations or man power of any kind need be chargeable to oil and gas transportation.

As to the onboard crew, these would be considered analogous to the crew of an ocean vessel, always on board but only part time on duty. The traditional caboose would disappear as an outworn relic of the past, replaced by television, and the entire crew would have "quarters" in a permanent car behind the lead locomotives. A total crew of three men would be sufficient for an entire 33-hr journey, being responsible only for inspection, emergency operation, and maintenance — one man on duty, one man available, and one man asleep.

TERMINAL FACILITIES AND OPERATIONS (FOR OIL AND LNG ONLY)

Loading

At Prudhoe Bay and Fort McPherson, the facilities chargeable to oil and gas transportation would be

1. A hot oil tank storage farm and automatic loading terminal and siding
2. A LNG liquefaction plant, tank farm, and automatic loading terminal
3. Emergency train maintenance and repair shops
4. Roadbed maintenance and repair shops (divisional).

The tank farm capacity at each place, using the two cases of Table 3, would need to be as follows:

	Million Gals	
	Phase B	Phase D
LNG	2.7	5.7
Crude Oil	1.0	2.2

Automatic loading and unloading of either oil or LNG with the train in continuous slow motion could be achieved by a "carousel," as described in reference (2), on a minimum radius 180-deg turn. In a unitrain, with tank interconnections, only every fourth or fifth car need be connected. In loading, only the tank top connection would be made, with a concentric vent hose. In unloading, a tank bottom connection would be made with a concentric blowdown hose.

The liquefaction plant at the northern terminals would employ the most efficient cryogenic cycle, an extra benefit being derived from the low-temperature environment. It is, therefore, possible, in these large quantities, to achieve a total liquefaction cost of 10 to 12¢/MKB, considerably less than the cost of producing LNG today. An extra economic credit at the northern terminals would be the large amount of heat available both from the 170 F oil and from the gas liquefaction process, both of which could be used for central heating the entire community.

At the LNG discharge terminal (Chicago, Minneapolis, or other), an extra economic credit is also possible in regasification. The LNG can be pumped into high-pressure tanks connected directly to the continental gas pipeline network. There its refrigerating capacity (-260 F and latent heat of 220 B/lb) can be "sold" to, say, meat packing or food-freezing industries, which would purposely locate such plants at the unloading terminal. Liquid nitrogen and oxygen could also be produced by direct heat transfer in enormous quantities. All such processes would "boil" the LNG, driving it into the pipelines without need of compressors. The total economic credits of selling refrigeration and eliminating pipeline entrance compressors would almost equal the liquefaction costs at the northern end, as shown in the economic analysis of Table 3.

ECONOMIC ANALYSIS

The economic analysis of Table 4 shows the cost in cents/million Btu of delivering oil and gas by the proposed system for two hypothetical demands of each called Phase B and Phase D (Table 2), which are estimated to be those of 1980 and 1990, respectively. The first case is analyzed assuming the primary system is only built and used; the second case assumes use of the total system of Table 3 and Fig. 1.

In both cases, note 1 assumes that half the supply of each fuel comes from Prudhoe Bay and half from the Mackenzie Delta, and that the annual fixed charges of the entire right-of-way and the cost of maintaining it is charged equally against the gas and oil delivered.

Other assumptions used in Table 4 are as follows:

Note 2: Trains per day shown are those on the main trunks, Ft. McPherson to Valleyview and Dawson to Valleyview; north of these points, the traffic is equally divided between the two sources.

Note 3: This indicates the total mileage in use, even though some is for LNG trains only, and some with half traffic.

Note 4: In Phase D, block speed on the primary trunk is assumed to increase to 60 mph, but not on the mountainous secondary trunk.

Note 5: Quantities of cars and locomotives include 10 percent extra for spares and maintenance.

Note 6: Operating crew numbers are calculated on the basis of six men per train-year, or a three-man train crew.

Table 4 Economic Analysis

	PHASE B		PHASE D	
YEAR	1980		1990	
SYSTEM	Primary		Pri. & Sec.	
DELIVERY (1)	Gas	Oil	Gas	Oil
10^6 lb/day	750	1000	2000	2600
10^{12} B/yr	6000	6600	16000	17000
Fraction U. S. Demand	21%	18.5%	50%	40%
Unitrains per track-day (2)	50		60	
Cars/string	128	107	142	115
Capacity/car. gals.	34000	25000	40000	30000
Route-miles used (3)	3320	1620	5390	3690
Avge. train speed (4)	50 mph		60/50 mph	
No. strings needed	482	232	828	578
No. cars needed (5)	67750	27300	129100	73050
No. loco units (5)	1062	511	1825	1274
Operating crew (6)	1446	696	2484	1734
CAPITAL COSTS CHARGEABLE TO OIL & GAS TRANSPORTATION, MILLION DOLLARS				
Roadbed (7)	1160	660	2080	1580
Cars (8)	3050	821	6455	2558
Locomotives (8)	159	64	320	191
ANNUAL COSTS, MILLION $/yr.				
Fixed charges on roadbed (9)	174	99	312	237
Fixed charges on cars (9)	456	123	968	384
Fixed charges on locos. (9)	64	26	124	76
Crew (10)	29	14	50	35
Administration and Control	5	3	10	6
Fuel (11)	-	5	-	12
MILLION $/yr.	728	270	1464	750
TRANSPORTATION COST IN ¢/MILLION BTU				
Origin-destination only:	12.3	4.1	9.3	4.4
Liquefaction and loading term'l	12	2	10	1.4
Unloading term'l & storage	3	2	2	1.4
Refigeration credit @ Chicago	-5.3	-	-5.3	-
NET TRANSP'N COST, ¢/MKB.	22	8.1	16	7.2
Equiv. $/bbl (@ 5.63 MKB/bbl)		.456		.405

Note: C.I.G.G.T. est. cost, for 2 million bbl/d or 624 million lb/day from Purdhoe Bay to Trout R. was $.670/bbl, using conventional railroad construction, and rolling stock and without benefit of combined LNG-and-oil unitrains.

Note 7: Total right-of-way costs assumed were as follows:

Primary trunk, south of Ft. McPherson---------------$800,000/mile
Primary trunk, north of Ft. McPherson-------------$1,000,000/mile
All mountainous lines of secondary system----------$1,000,000/mile
Converting existing rail to double track, wide gage--$400,000/mile
Converting existing double track to wide gage----------$200,000/mile

Note 8: Rolling stock costs were assumed as follows:

	Phase B	Phase D
LNG car and truck	$ 45,000	$ 50,000
Oil car and truck[3]	$ 30,000	$ 35,000

Gas turbine locomotives, plus train controls and truck motors: LNG trains $550,000 $650,000

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[3] Recent construction of 100-ton coal hoppers by the N.&W. Railway cost $12,650 each, and of 100-ton gondola cars cost $14,500 each.

Note 9: Fixed charges in percent assumed as follows:

	Interest	Dep'n.	Maint.	Taxes	Total, %
Roadbed	6	2	5	2	15
Cars	6	4	3	2	15
Locomotives	6	5	7	2	20

Note 10: All crew costs assumed $20,000/yr per man.

Note 11: Fuel costs charged proportionate to ton-miles of each cargo. LNG delivered diminished by 2 percent and 3 percent, respectively.

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